IMPELLER PUMPS FOR PUMPING BLOOD OR SIMILARLY DELICATE FLUIDS

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Abstract

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(54) IMPELLER PUMPS FOR PUMPING BLOOD OR SIMILARLY DELICATE FLUIDS

(71) We, BIO-MEDICUS, INC., a body corporate organised according to the laws of the State of Minnesota, United States of America, having its principle office at 803 Washington Avenue S.E., Minneapolis, Minnesota, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to apparatus for pumping blood of a living person, or of a living animal, to replace one or more pumping functions of the human or animal heart in case of disability thereof. The heart replacement may be partial or complete, internal or external. While the pumps provided according to the invention are provided principally for pumping blood, it will be apparent that the pumps may be employed in other instances for pumping other delicate fluids. The pumping equipment provided by the invention has rotating fluid impellers. The pumps are adapted for pumping of blood and other delicate fluids without any pronouced physical effect on the blood or other fluid being pumped. The pumps are designed to reduce the effects of sudden pressure changes, impacts, rapid changes in direction of flow, in order to prevent injury to or destruction of the pumped fluid and its components. Various electrical drive assemblies may be provided for motivating or rotating the impellers employed in the pumps.

The pumps are adaptable for use disposed within a body cavity, for example as replacements for either or both of the pumping functions of the heart. The pumps herein provided may also be used for pumping blood externally of the body. The pumps do not require the use of valves, such as those of the heart, but valves may be provided if desired.

Blood is a complex and delicate fluid. It is essentially made up of plasma, a pale yellow aqueous liquid containing dissolved salts and protein and the "formed elements", which are microscopic materials including the red corpuscles, white corpuscles, and platelets. These and the other constituents of blood, as well as the nature of suspension of these materials in blood, are fairly readily affected by the manner in which blood is physically handled or treated. Blood subjected to mechanical shear, to impact, to depressurization, or the like, may be seriously damaged. The balance between the blood constituents may be affected. Commencement of deterioration may result from physical mishandling of blood. Blood which has been damaged may be unfit for use.

A pump for replacing one or more pumping functions of the heart should therefore be capable of repeatedly pumping the same blood, time and time again, without damaging the blood, at least not more than to the extent where the body can function to repair or replace the blood components and eliminate damage and waste materials therefrom.

The invention provides a pump for pumping blood or similarly delicate fluids, which comprises impeller means including at least two spaced, generally frusto-conical, coaxially mounted vaneless impellers arranged to cause, on rotation, substantially non-turbulent flow in fluid between them, and at least one of the impellers being provided with an aperture at its narrower end so as to allow fluid to be introduced between the impellers at a position generally at the axis of rotation, housing means enclosing said impellers, means for simultaneously rotating said impellers about said axis to cause the fluid to move radially outwards, and outlet means to allow said fluid to leave the housing means from between the outer peripheries of the said impellers. Use of such a pump has the effect that the blood or other delicate fluid is handled gently, with minimum shear, shock, vibration, impact, pressure or temperature change, or any other condition or treatment which would unduly damage the blood or other fluid. Essentially non-turbulent flow is maintained by accelerating the fluid gradually and smoothly.

The pumping action obtained may be described as radially increasing pressure gradient pumping, or in some cases more specifically as constrained force-vortex radially increasing pressure gradient pumping. In centrifugal pumps, the fluid acted on by the vanes of the impeller is positively driven or thrown outwardly (radially) by the vane rotation. The fluid as it moves from the vanes to the ring-shaped volute space beyond the tips of the vanes is reduced in velocity, and as the velocity decreases the pressure increases according to Bernoulli's theorem. On the other hand, in the pumps provided according to this invention, the pumped fluid is not driven or thrust outwardly but instead is accelerated to circulate in the pumping chamber at increasing speeds as it moves farther and farther from the centre. The speed is at a maximum near the outer periphery of the impellers.

While the impellers can take a variety of different forms in pumps according to the invention, the specified vaneless frusto-conical configuration common to all forms has the consequence that the impellers act to increase the swirling speed of the liquid passing through the pump, but do not act to drive or throw the liquid toward the periphery or volute of the pump chamber, but instead only increase the rotational speed of the liquid. As the rotational speed of the liquid is increased, it achieves a more remote "orbit" about the centre of the impellers and moves toward the periphery of the chamber.

The pumps may be provided with internal driving means in the form of an electric motor drive of some form. The electrical parts of the electrical motor drive may be presented in several different forms.

Several forms of pump in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is an axial cross-sectional view of one form of pump having a built-in drive motor for the impeller assembly of the pump;

Figure 2 is a vertical cross-sectional view taken at line 2—2 of Figure 1;

Figure 3 is an axial cross-sectional view showing another form of pump;

Figure 4 is a partial cross-sectional view taken at line 4—4 of Figure 3;

Figure 5 is an axial cross-sectional view of a third form of pump;

Figure 6 is a cross-sectional view of another form of impeller useful in connection with the invention; and

Figure 7 is an axial cross-sectional view of a fourth form of pump, having a built-in drive motor.

With initial reference to Figs. 1 and 2 of the drawings, a plurality of flared, generally frusto-conical, coaxially mounted impellers 35, 36 and 37 are connected together by a plurality of rods 38 spaced about the impellers. Impellers 35 and 36 have circular, axial openings at their smaller ends designated respectively by reference numerals 39, 40. Impeller 37 has a convex rounded center 42 which is connected to a shaft or rod 43 which is rotatively disposed through an opening of housing end portion 45. Housing portion 45 is inwardly curved corresponding to the curvature of impeller 37 and the impeller is spaced therefrom as shown. The smaller end of impeller 35 outwardly of opening 39 thereof is rotatively sealed within the housing 48 by a circular seal 49, for example, an O-ring, and a bearing 50 is provided adjacent the seal. Housing 48 is curved so as to correspond to the curvature of the impeller 35.

The three impellers are arranged to rotate together when driven as will be described. The impellers 35 to 37 are each permanently magnetized to have alternate magnetic north and south pole "N" and "S" spaced therearound as indicated in Fig. 2 by reference numerals 51, 52, respectively, of impeller 36. The other two impellers, 35 and 37, have magnetic poles therearound in positions corresponding to the pole positions shown for impeller 36. The windings of the electrical motor assembly are indicated by reference numeral 54, and are disposed within housing 48 around the outside of the outer edges of impellers 35 to 37. Separate magnets may be connected to the impellers, instead of the impellers being magnetized, if desired.

Housing 48, at its lefthand end as shown in Fig. 1, is curved so as to correspond to the curvature of impeller 35. An inwardly projecting thickened wall portion 55 surrounds the fluid inlet to the pump. The portion 45 of the housing is, as has been described, inwardly curved corresponding to the curvature of impeller 37, and is flat at its outer side. The surrounding portion 57 of the housing wall has a winding 54 disposed therein, extends around the outer edges of the impellers and is spaced outwardly uniformly therefrom. The inner surface of wall 57 has a pair of circular beveled-sided annular projections 59, 60 which are centered between the impellers 35, 36 and 37, respectively.

The electrical switching elements for the windings 54 are disposed inside the housing portion 45 at 62. The rod 43 is journaled through bearing 63 and serves to rotate the necessary switching elements at 62. The switching elements 62 are connected to the windings in customary fashion, these connections not being shown in the drawings because they are of standard conventional form in order that the winding currents may be altered as required for the apparatus to perform its rotational motive function. An electrical power source for the drive motor is provided and is connected to leads 65a, 65, the power source being of any convenient

nature. When electrical current is supplied to the windings through switching elements 62, the magnetic impellers rotate. Fluid enters the pump through the opening within thickened wall portion 55 and flows between impellers 35 and 36 and between impellers 36 and 37, reaching these areas through impeller openings 39 and 40. Since there are no vane surfaces to directly force the fluid radially outwardly, as in a conventional centrifugal pump, friction between the impellers and the fluid causes the fluid to commence circulating round and round in circular fashion, and gradually moving outwardly toward the pumping chamber periphery. The housing has an outlet 64 shown to be more or less tangential of the chamber periphery, but which may be directed in any flow direction from the chamber. Fluid, the velocity of which has been increased by rotations of the impellers, is caused to move under pressure out of outlet 64 to accomplish the pumping function of the pump. Arrow 65 indicates the direction of impeller rotations.

The electric motor thus provided may be of any of the known types, AC or DC, with or without commutation, powered by electrical conductors leading thereto from any suitable AC power source or from a battery, located either internally or externally of the body. The conductors may be disposed through the outer body wall from the exterior of the body, installed surgically. The power source may include capacitance connections across the body wall, with both of its plates beneath the skin, or with one plate interior of the skin and the other exterior of the skin. A battery power source may be disposed within the body, replaceable periodically by surgery, and rechargeable inductively from the exterior of the body. Batteries capable of operation for periods in excess of two to three years are available so that surgery for their replacement would need to be done at appropriate intervals.

Referring now to Figs. 3 and 4 of the drawings, the housing 70 is of the same general form as housing 48 of Figs. 1 and 2. A plurality of impellers 71 to 74 are disposed within the pumping chamber, the outermost impeller 71 being rotatively sealed by a circular seal 76, for example, an O-ring, and journaled in a suitable ring bearing. The housing has a thickened wall portion 77 around the fluid inlet to the pump and the successive impellers 71 to 74 have progressively smaller circular flow passages 78 to 81 affording fluid flow to between the spaced apart impellers. The impellers are connected by circularly spaced elements 83 to rotating magnet body 84. Body 84 carries a concentric shaft 85 which is journaled in a bearing 86. The end 87 of magnet body 84 is flaringly curved corresponding to the curvature of impeller 74 and is spaced therefrom by a distance about equal to the impeller spacings. Magnet body 84 has therearound alternating north and south poles permanently magnetized therein. The connection elements 83 are of streamlined cross section as is best shown in Fig. 4. The rounded edges 88 of the elements 83 are the leading edges which are rotated through the fluid being pumped and the shapes of the elements provide streamline flow therearound whereby turbulence is not caused by the elements 83. The pump of Figs. 3 and 4 has imbedded in housing 70 the windings 89 similarly as the windngs 54 are provided in Figs. 1 and 2. The electrical switching elements for the windings are disposed in a chamber 91 which is provided at the end of rod or shafts 85. The electrical connections between the switching elements and the windings are not shown as they are conventional in nature. Electrical power is supplied through electrical leads 92, 93, from a suitable power supply, not shown.

In order that the volume flow remains approximately constant past all radial distances from the fluid inlet to the impeller periphery, the impeller passages (spacings between impellers) should decrease in size as an inverse function of the radial distance from the impeller axis. This is shown in Figs. 5, 6 and 7. This prevents adverse affects on the fluid such as cavitation, pressurization, depressurization, and the like, from occurring inside the pumps, thereby preventing undesirable shock and damage to the fluid being pumped.

The shape of the impellers in Figs. 5 and 6 is such that the outward fluid flow volume is constant from the inner edges of the impellers to the outer peripheries of the impellers. The impellers are closer together at their peripheries such that the volume of outwardly flowing fluid per unit of time at the periphery is the same as the volume of outwardly flowing fluid per unit of time at any circle inward of the impeller peripheries.

In the drawings, the equipment shown is schematic and not to scale, the outward convergence of the impellers actually can be considerably greater than shown, with the impellers being closer together at their outer edges or peripheries, and with the flow as described in the preceding paragraph.

In Fig. 5 the pump shown has plural impellers 94*a*, *b*, *c*, and *d*, which are of a straight-sided frusto-conical configuration, with the sides sloping at different angles so that the impellers converge together towards their outer peripheries. Housing 97 is shaped to conform with the shapes of the outer impellers, and has entrance upset 98 to receive impeller 94*a* nipple 99 sealed by O-ring 100. Shaft 102 is journaled for rotation through bearing 103. The impellers are joined by bars 104. The housing parts are connected

at flange connection 106. Housing 97 has tangential fluid outlet 108 from annular circulation space 110.

In Fig. 5 embodiment of apparatus, the inner edges of impellers 94b, 94c are flared toward the inlet 112, such that approximately the same volume of fluid will enter from the inlet to each of the three spaces between impellers.

Referring to Fig. 6, there is shown an impeller arrangement wherein the pair of impellers 114, 115 are double curved between their centres and peripheries, the impellers being mutually convergent, as previously described, to achieve uniform volume flow at all radial extents of the impellers.

The spacings between the outer peripheral edges of the impellers may be very close, i.e. a few thousandths of an inch, or may be larger. Inwardly of the impeller outer edges, the spacings become increasingly larger. Close peripheral spacings do not cause unacceptable trauma to blood but do enable the pump to work efficiently. The efficiency of the pump is directly related to the transfer efficiency of the impellers which is a function of the impeller spacing. There exists an "optimum" spacing for each set of impellers, at which the pump efficiency is at a maximum. However, if the close spacings are maintained over a considerable radial extent, then excessive trauma to blood does tend to occur. Nevertheless, the predominant effect exerted by the spacing on efficiency takes place at the largest radii. Thus close spacing need only be maintained at the periphery. Therefore, the impellers can be made with the continuously outwardly decreasing spacings as herein described and thus low traumaticity can be combined with high efficiency.

The convergence of the impellers, whereby the flow space therebetween diminishes towards their outer peripheries, prevents cavitation (dissolved gases coming out of solution to form bubbles because of the pressure reduction within the pumps), which would adversely affect pumping efficiencies and cause damage to certain fluids, such as blood. The convergence of the impellers may be such that the flow rate can either increase outwardly or decrease outwardly, accompanied by corresponding pressure changes on the fluid being pumped. In the outer annular flow spaces between the impellers maximum fluid velocity is maintained, so that conversion of velocity to pressure occurs at the outer pump housing and as fluid enters the pump outlet.

Referring to Fig. 7, there is shown a pump 150 the design of which eliminates the use of seals between the impellers and housing. The housing consists of two parts. Housing part 151 is flaringly enlarged from end 152 around fluid inlet 153 and has a flat surface 154 around its outer edge to abut a ring-shaped clamp nut 155. Nut 155 extends beyond the end of the housing and is internally threaded. Housing part 157 is outwardly cylindrical and has threads at its open end onto which nut 155 is screwed to connect housing parts 151, 157 together. A seal 158 is disposed in a groove around the annular end of housing part 151 to make the connection leak-proof.

A tangential outlet port 159 is provided from the side-wall of housing part 157. At the center of the closed end 161 of housing part 157, an opening is provided to receive shaft 162, journaled in bearing 163, and surrounded by seal 164, the bearing and seal being disposed in annular enlargements around the shaft opening.

End wall 161 is inwardly thickened toward its center. The inner end of shaft 162 is of conical shape, and a plurality, preferably three, small-diameter streamlined rods 166 depend angularly from the shaft end at equal angles and equally spaced. A plurality of impellers 168 to 171 of different flared curvatures are supported by the rods 166. The impellers 168 to 171 have holes therethrough to receive the rods 166, impeller 168 being positioned at the ends of the rods, and impellers 169 to 171 being spaced between impeller 168 and the end of shaft 162. The impellers are fixed to the rods by press-fitting, or by any other suitable means.

The impellers 168 to 171 have circular center openings 168a—171a of sequentially smaller size. The spacing between the centers of impellers 168 and 169 is larger than the spacing between impellers 169 and 170, which is larger than the spacing between impellers 170 and 171. Impeller 168 is spaced from the inside of the flared wall of housing part 151, and impeller 171 is spaced from the flared inside surface of end wall 161 of housing part 157.

The between-the-impeller spacings decrease outwardly as in the embodiments of Figs. 5 and 6. However, the spacings between the walls of the housing and end impellers impellers 168 and 171, increase outwardly. The reason for this is that, because the housing walls do not rotate, and because the impeller and fluid angular speeds increase outwardly, the shear on the fluid would increase outwardly if the end spacings were uniform or decreased outwardly. Therefore, in order to avoid increased shear on the fluid as it circulates outwardly to the impeller peripheries, the end impeller housing spacings are increased outwardly.

Referring now to Fig. 7: of a fixed volume of fluid which has entered through inlet 153, a certain amount will be directed around each impeller encountered in turn as the fluid flows towards the right, as seen in the drawing. The impeller center openings 168a to 171a are sized to receive the remaining flow

at later impellers after partial flow has been diverted by earlier impellers. The unequal inner periphery spacings between the impellers are required by the more sharply flared shapes of earlier impellers as compared with later impellers.

The motor-pump structure of Fig. 7 has a partitioned housing, the impellers being disposed within one chamber of the housing and the magnetic armature element being disposed in a separate chamber. Shaft 162 extends into the separate chamber, wherein it carries a circular disc magnet 175 having spaced thereardound alternating north and south poles of permanent magnetism as previously described for the other embodiments. The magnetic disc 175 is affixed flush against a thicker disc 176 which rotates therewith. Shaft 162 extends into a terminal bearing 177. The housing is flat at its end 178. A chamber 179 formed on the end 178 of the housing contains the electrical switch elements for the motor winding 180 which is disposed as before within a circular annular chamber of the housing, outwardly surrounding the magnetic disc 175. Upon supply of electrical power to the motor windings 180 through the switching elements in chamber 179, the magnetic disc 175, disc 176 connected therewith, and the impeller elements 168 to 171 rotate to pump fluid entering through the inlet 153. Again the pump has no impeller vanes to cause fluid to be thrust radially outwardly within the pumping chamber, and the fluid is caused to rotate circularly with constantly increasing radius, to be expelled through outlet 159 from the housing. The outlet 159 may be similar to outlet 64 of the Figs. 1 and 2 device.

It will be appreciated that in all of the arrangements described, the positions of the magnetic pole means and motor windings may be interchanged. That is to say, the magnetic pole means may be on one or more of the impellers or associated with the impeller means, or may be mounted on the housing. Similarly, the windings may be either located in or on the housing or associated with the impeller means, as the case may be.

As shown in Figs. 1, 3 and 5 the fluid inlet through the housing wall and the initial impeller through which the fluid passes, may be smoothly merged so that there are no abrupt changes of fluid flow therepast. In each case, the fluid to be pumped flows between rotating impellers, to be driven by friction with the impellers to adopt a generally circular flow. The pumps operate on a constrained force-vortex principle, there being no impeller surfaces in the pumps for impelling blood or other fluid material being pumped radially outwardly toward the periphery of the pump chamber. A constrained force-vortex pump operates on the principle that a rotating chamber causes rotation of its contents, with creation of a vortex, so that a body of circulating fluid is maintained within the rotating chamber by rotation of the impellers which comprise the sides of the chamber. The rotational speed of liquid in the pump is increased from the center to the periphery of the pumping chamber. The liquid is discharged at the peripheries of the impellers.

It will be seen that the blood is not submitted to any substantial agitation by the rotation of the impellers, or by any other portion of the pump apparatus. There are no sudden changes in direction of flow through the pumps, all joints between surfaces being smooth and all surfaces over which the fluid flows being smooth. Where there are more than two impellers there is more than one space in which the fluid is rotated and pumped. According to this invention, the emphasis is on gentle, efficient, non-turbulent handling of the pumped fluid.

It will be realized that pumps may be provided with any number of pumping stages, and may include individual pumping stages of any of the types mentioned herein, and in any combination.

In the case of each of the pumps and impellers shown in the drawings, it will be noted that the impellers are designed to avoid turbulence and to avoid rapid pressuring and depressuring of the blood being pumped, and also to avoid any physical grinding or abrasive action upon the fluid. As has been made clear, these impeller designs are made in this manner in order that blood or other delicate liquids or gases being pumped, some containing solids in suspension, will not suffer detriment and will not be destroyed by the pumping operation.

In contrast to centrifugal pumps, the revolution speeds permitted of the impellers employed with the pumps herein shown and described are kept minimal. The several impeller designs presented are each of a form adapted to pregressively increase the circular fluid velocities as the impeller turns and as the fluid advances toward the periphery of the impellers. In each pump presented, an annular fluid circulation space is provided which is entirely unobstructed and regular so that fluid can circulate therein without turbulence or baffle effects.

The pumps and their parts may be constructed of any materials compatible with their intended use, including metals, mineral materials, plastics, rubbers, wood, or other suitable materials. With pumps in which the winding of the electric motor is situated inside the housing, it is convenient to seal the winding from fluid contact by means of a layer of plastics material. When blood is to be pumped, consideration must be given to biological compatibility so that trauma to the blood will not result. Materials such as that

sold under the name "Teflon" (Registered Trade Mark), isotropic carbon, silicone rubber, certain plastics and a mesh made from material sold under the name "Dacron" (Registered Trade Mark), upon which a neo-intima can grow, have been successfully used in contact with blood, without traumatic effects, and may be used in construction of the pumps for blood pumping adaptions. Non-corrosive metals and alloys may be used in the pumps where required.

The housings and impellers may be constructed of suitable material so that the housing may be rigid, semi-rigid, or elastic in whole or in part. The non-rigid construction can be used for imparting pulse configurations to blood in heart simulation pumps.

While the impellers shown herein may in some cases perform better when rotated in one direction, it should be understood that they may be rotated in either direction without other modification of the pumps.

WHAT WE CLAIM IS:—

1. A pump for pumping blood or similarly delicate fluids, which comprises impeller means including at least two spaced, generally frusto-conical, coaxially mounted vaneless impellers arranged to cause, on rotation, substantially non-turbulent flow in fluid between them, and at least one of the impellers being provided with an aperture at its narrower end so as to allow fluid to be introduced between the impellers at a position generally at the axis of rotation, housing means enclosing said impellers, means for simultaneously rotating said impellers about said axis to cause the fluid to move radially outwards, and outlet means to allow said fluid to leave the housing means from between the outer peripheries of the said impellers.

2. A pump as claimed in claim 1, wherein the conical portions of the impellers all flare outwardly in the same sense.

3. A pump as claimed in claim 1 or claim 2, wherein the impellers converge together towards their outer peripheries.

4. A pump as claimed in any one of claims 1 to 3, wherein the conical portions of the impellers flare away from the axis along straight lines.

5. A pump as claimed in any one of claims 1 to 3, wherein the conical portions of the impellers flare away from the axis along curved lines.

6. A pump as claimed in any one of claims 2 to 5 wherein the impellers converge together towards their outer peripheries in such a manner that, in operation, the volume flow of fluid is substantially constant at all radial positions along the conical portions of the impellers.

7. Apparatus as claimed in any one of claims 1 to 6, wherein there is provided electric motor means comprising magnetic pole means associated with either the impeller means or the housing means, winding means associated with the impeller means, or the housing means, as the case may be, and means for supplying electric current to the winding means, the arrangement being such that, on supplying the winding means with electric current, the impeller means rotates to pump fluid through the housing means.

8. Apparatus as claimed in claim 7, wherein the magnetic pole means comprise magnetized portions of the impeller means.

9. Apparatus as claimed in claim 8, wherein the magnetic pole means are provided in each impeller.

10. Apparatus as claimed in claim 7, wherein the housing means has a second chamber coaxial with a pumping chamber containing the impellers, disc means disposed in the second chamber coupled for rotation with the impellers, seal means around said coupling to prevent fluid flow from said pumping chamber into said second chamber, said magnetic pole means comprising magnetized portions of said disc means.

11. Apparatus as claimed in claim 7, said winding means being in said housing means and being sealed from fluid contact by plastic layer means.

12. A pump for blood or other similarly delicate fluids, substantially as hereinbefore described with reference to, and as shown in Figs. 1 and 2, Figs. 3 and 4, Fig. 5 or Fig. 7 of the accompanying drawings.

13. A pump for pumping blood or similarly delicate fluids as claimed in claim 1, including impellers substantially as hereinbefore described with reference to and as shown in Fig. 6 of the accompanying drawings.

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1383811 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG. 1

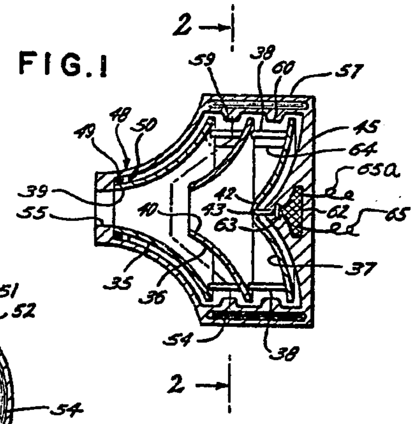

FIG. 2

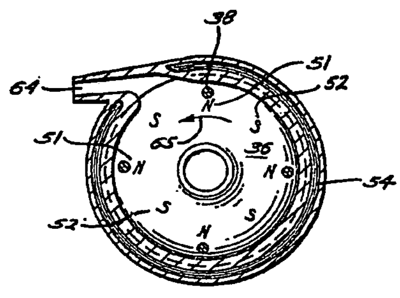

FIG. 3

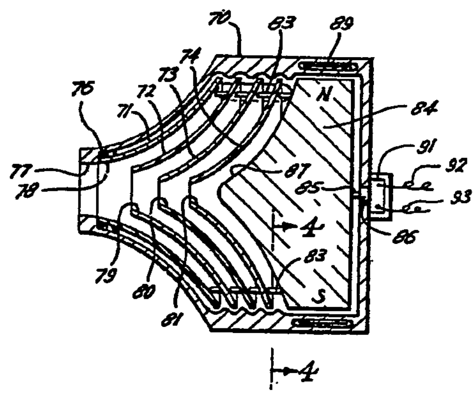

FIG. 4.

FIG.5

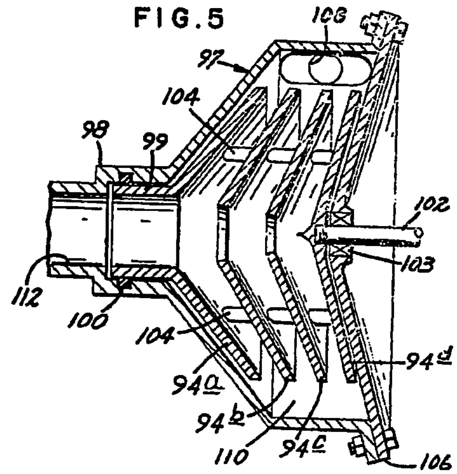

FIG.6

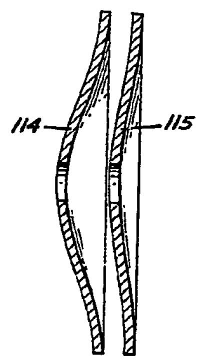

FIG.7